Clinical options for mandibular reconstruction: a review

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Abstract

This paper reviewed the different clinical options for reconstruction of segmental defects of the mandible. The options reviewed included no reconstruction; the use of prosthetic implants (alloplasts); autogenous bone grafts; combination of allopplasts with autografts; free pedicled compound grafts;combination of homografts and autografts; distraction osteogenesis; and tissue engineering. The goal, objectives, criteria for success of autogenous and alloplastic reconstructions were highlighted as well as the factors that may influence the choice of a particular method.

Introduction

The mandible is a major component of the human face. It provides a mobile platform for the dentition and a mobile frame for insertion of masticatory, tongue and suprahyoid muscles. It plays important functional roles in mastication, speech, deglutition, phonation, oral competence and facial aesthetics[1-3]. Reconstruction of mandibular defects is one of the most challenging operations that a surgeon can encounter because a satisfactory functional as well as a good aesthetic outcome must be concurrently achieved[4-6]. Recently, Tin et al.[7] submitted that surgeons have been trying to reconstruct the mandible for more than a century and despite the enormous progress made over the last 40 years, the ideal system for mandibular reconstruction has not been developed.

Since Martin[2] described the immediate restoration of a resected segment of the mandible with a prosthetic appliance in 1889, several methods have been employed to reconstruct the mandible. These included Kirschner wire and metallic plates (essentially space maintainers), titanium or stainless steel, plastic (Dacron and polyurethane) trays with cancellous bone chips (alloplast – auto graft combination), bank bone (homografts), re-use of resected mandible after freezing in liquid nitrogen, boiling or sterilization with radiotherapy, calcium sulphate - cyanoacrylate material, particulate dentine – plaster of Paris combination, autogenous grafts, pedicled osteomyocutaneous flaps and microvascular transfers of bone and soft tissue[2 - 11].

The size and complexity of the defect have been reported to influence the outcome of mandibular reconstruction by several authors[12-15]. Jewer et al[16] Hemi-Mandibular-Central-Lateral classification of mandibular segmental defects took cognizance of the complexity of the reconstruction rather than the size or anatomic location of the defect. This review will discuss the advantages and disadvantages of the different options the surgeon can use to reconstruct mandibular segmental defects and highlight factors that can influence a successful outcome.

Goal, objectives and success criteria

Several authors have expressed slightly different views concerning the goal of mandibular reconstructions. Jewer et al[16] submitted that the aim of oro-mandibular reconstruction is that "every man should eat, drink and enjoy the fruit of his labour, it is the gift of God" (Ecclesiastes 3: 13). Lavertu et al[17] also submitted that the goal is to restore a solid arch that will articulate properly with the maxilla and restore function, aesthetics and quality of life. Marx[12] specified the objectives of mandibular reconstruction as the restoration of long term form and function, the achievement of a satisfactory articulation with the maxilla, a satisfactory facial cosmesis and dental rehabilitation. Farwell and Fultran[5] believed the goals should ideally include maintaining the pre-morbid occlusion, avoiding trismus, achieving dental restoration and preventing salivary fistula. Urken et al[18] submitted that the ultimate goal is mastication.

Different authors have expressed varied opinions as to how to measure the success of mandibular reconstructions. Lawson and Biller[3], submitted that success should be judged by the restoration of continuity of the mandible, establishment of adequate contour and ability of the patient to achieve functional dental prosthetic rehabilitation. Lew and Hinkle[13] submitted that a successful reconstruction should produce a mandible that is strong enough to resist fracture during function, have sufficient alveolar ridge size to carry a prosthesis and be aesthetically acceptable to the patient. However, Marx[19] listed five specific criteria for determining the success or failure of mandibular reconstructions:

1. Restoration of jaw continuity-clinical as well as radiological evidence of bony union.
2. Restoration of arch curvature and good occlusal relationship with the maxilla.
3. Long term maintenance of osseous bulk.
4. Functional prosthetic rehabilitation.
5. Restoration of acceptable facial cosmesis.

Before any bone grafting can be said to be successful all of the above five criteria must be achieved on long term basis[19].

Reconstruction options, indications, advantages and disadvantages.

Factors influencing choice of method Davidson and Gullane[20] submitted that the numerous methods and techniques developed for mandibular reconstruction is a reflection of the fact that 'no one method is appropriate for every situation and no single technique is ideal'. They submitted that the ideal method should be one-staged, fast, easy, desirable and reliable, and must concurrently achieve a good cosmetic and functional outcome.

In the past, the great debate had been between advocates of immediate and delayed autogenous reconstruction for decades[3, 5, 12, 21, 22]. The advent of microvascular free tissue transfer appeared to have favored advocates of immediate reconstruction with all the advantages of composite hard and soft tissue transfer[14, 16, 23-27]. However, as Schimele[6] submitted, many factors must be considered when developing a treatment plan for each patient:

1. Patients desires, motivation and social or professional activities.
2. Patients finances- particularly in poor developing countries.
3. The severity of the functional and aesthetic impairments – strictly lateral defects, small defects of the ramus and isolated condylar defects with minimal aesthetic and functional impairments may be left unreconstructed.
4. Prognosis of the disease and life expectancy – risk of recurrence of malignant tumors may dictate a fast alloplastic reconstruction or a delayed approach.
5. Surgeons training and skills- particularly with regards to micro-vascular surgery. Being competent in micro-vascular surgery should not tempt the surgeon to deploy it to reconstruct all cases. Small segmental defects with well preserved periosteum and no soft tissue loss may be reconstructed with free autogenous bone.
6. Facilities available in the hospital.
7. Patients age - the very old and the very young.
8. General medical condition of the patient.

Clinical options

There are presently eight major clinical options available to the surgeon to reconstruct a segmental defect of the mandible[2, 3, 12, 13, 28, 29].

1. No re-construction.
   Coronoid defects, isolated condylar defects and small lateral defects of the horizontal and vertical ramus may be left unreconstructed depending on the desire of the patient because they result in minimal aesthetic or functional deficits **(Figure 1 a, b, c & Figure 2 a, b, c).**
2. The use of prosthetic implants (Alloplasts).
   This entails the use of inert materials as space maintainers (Kirschner wire, titanium bone plates or formed appliances). Other materials that have been used included stainless steel, vitallium, tantalum, titanium, silastic (dimethylsiloxane), teflon (fluoroethylene), acrylic (polymethylmethacrylic), polyurethrane and dacron mesh.
3. Cortico-Cancellous bone grafts.
   This consists of the use of fresh autografts from the rib, iliac crest, tibia and scapula. In addition, treated autografts such as freeze dried irradiated or autoclaved

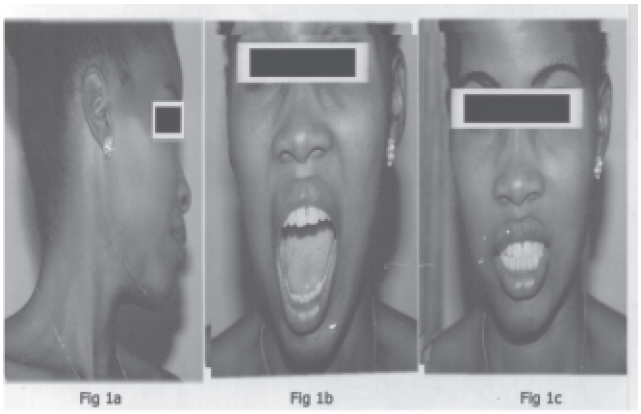

Figure 1a,b,c: Post operative appearance of a patient with a true lateral defect following segmental resection for cemento-ossifying fibroma

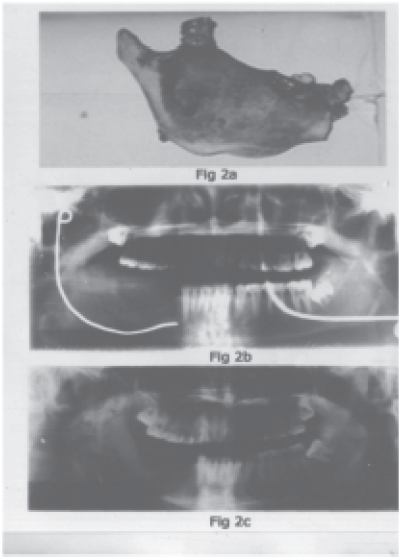

Figure 2a,b,c: Spontaneous regeneration of hemi-mandible following resection for classic intraosseous ameloblastoma in a 15 years old male patient.

bone may be used. Lawson et al[30] reported a failure rate of 30 to 50% with immediate cortico-cancellous cellular bone grafts. They observed that failure occurred largely because of exposure to the oral cavity and its microbial content. Marx and Ames[31] popularized the concept of delayed secondary reconstruction of mandibular defects. They reported a 3% rate of infection with graft loss, 2% partial graft loss and 2% wound dehiscence. It is generally agreed that the degree of vascularity of the graft bed, a stable fixation and an aseptic operating environment are important factors influencing the success of non-vascularized bone grafts[2, 3, 13, 22, 30]. Presence of nonvital teeth, foreign bodies, haematoma formation, wound dehiscence and oral perforation are factors identified to adversely affect the success of cortico-cancellous bone grafts[2, 3, 13, 22]. Lawson et al[30] identified wound infection from salivary contamination as the sole factor responsible for the difference in success rate of immediate and delayed cortico-cancellous bone grafting. The biologic activity of autogenous cancellous bone is due to its histocompatibility, large surface area covered by osteoblasts and pre-osteoblasts and its trabecular architecture. The host response to cancellous autografts essentially consists of five overlapping stages[32].

I. Haemorrhage and inflammation – occurs immediately after the surgery.
ii. Death of osteocytes in trabecular lacunae and survival of surface osteoblasts (which results in early new bone (osteoid) formation.
iii. Infiltration of porous cancellous bone graft by host vessels, osteoblasts, preosteoblasts from the periphery (graft bed) towards the center. This occurs approximately 2 days after surgery.
iv. Osteo-conduction and early graft remodeling. Osteo-conduction, involves the resorption of the graft by osteoclasts and the deposition of new bone by osteoblasts which line the edges of dead trabeculae and deposit a seam of osteoid which surround the central core of dead bone. Graft remodeling involves osteoclastic resorption of the new host bone and entrapped cores of necrotic bone. These are then replaced with new bone synthesized by host osteoblasts. Osteo-conduction and remodeling may last for several months in cortico-cancellous grafts.
v. Integration of the graft into a streamlined mechanical structure. This may last for 6 to 12 months after surgery. The union between the bone graft and host bone is dependent on the stability of the graft -host construct – that is a stable (rigid) fixation and close contact between the host and the graft [30, 32]. It is the responsibility of the surgeon harvesting and fixing a cortico-cancellous bone graft to ensure[13]:

1. Removal of all devitalized bone, teeth, roots and adjacent foreign bodies at least 8 weeks prior to surgery.
2. Sterility of the graft intraoperatively
3. Minimal exposure to air and heat post harvesting
4. A healthy, vascular host bed (all scar tissue in the host bed must be excised)
5. That marrow rich margins abut the graft
6. Reduction or total elimination of hematoma formation
7. Early use of the graft site (which stimulates blood flow and osteogenesis) - rigid fixation is essential

4. Combined alloplast – autograft
In this case, alloplasts are used to fix the autograft (for example bone plate with cortico-cancellous bone – **Figure 3a, b, c)** or used to carry cancellous cellular bone chips (CCBC) in form of a mesh of stainless steel or titanium. When reconstruction plates are used they should be removed later to allow the bone to be subjected to normal local mechanical stimuli (to prevent stress shielding). However, because titanium meshes are flexible and are able to transmit functional stresses to the grafted bone, it need not be removed after the graft has taken[33]. Apart from stainless steel and titanium, other materials that have been used to carry cancellous cellular bone grafts include Dacron-coated polyurethane trays, biodegradable polylactide and polyDL lactide trays, allogeneic cribs, autogenous cribs and reimplantation of resected mandible[7]. The advantages of CCBC grafting when compared with microvascular reconstruction include[7, 34] .

a. An inherent potential for anatomic reconstruction of any part of the mandible.
b. Ability to adequately support implants and prosthesis.
c. Reduced donor site morbidity.
d. The potential to bridge defects of any length (even the whole mandible) when combined with costochondral graft for condylar reconstruction.

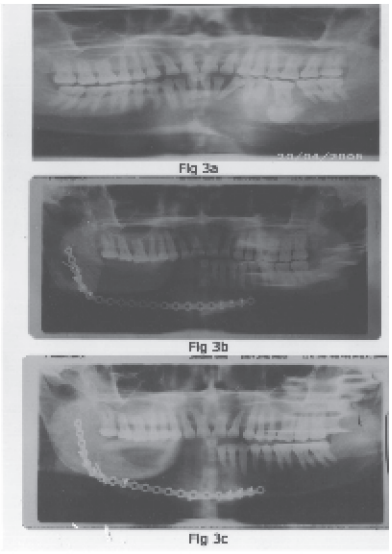

Figure 3a,b,c: a=preoperative OPT showing multilocular rediolucency with periapical radio-opacity around the first molar roots with destruction and expansion of the mandibular inferior border. b=OPT after resection and immediate fixation of 2.4 locking titanium reconstruction plate c= OPT after delayed (3 months postoperative) cortico-cancellous iliac crest bone graft.

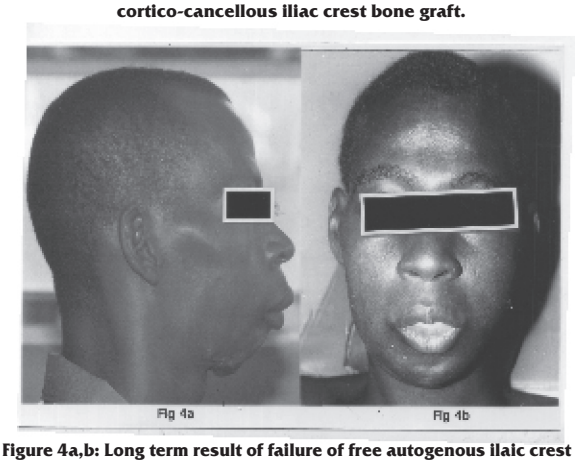

Figure 4a,b: Long term result of failure of free autogenous iliac crest reconstruction in defects involving the symphysial region: Note the classic 'bird face' deformity

The limitations of CCBC include remodeling resorption and wound dehiscence. It is not recommended in situations of soft tissue compromise or when radiation therapy has been or will be used. Furthermore, complications may arise from the cribs used to carry the CCBC (exposure, infection, foreign body reactions)[7, 35].

Two conflicting theories were proposed for cancellous cellular bone healing: [35]

The osteoblastic theory of Ollier and Axhausen which held that viable bone marrow (osteoblasts) and periosteum survived the transplantation.

a. The induction theory of Phemister and Urist which suggested that the entire graft underwent an aseptic necrosis and was replaced with bone produced by the connective tissue stem cells of the host-recipient bed or host bone ends ('creeping substitution.') Carlson and Marx[35] proposed the two-phased theory of CCBC bone regeneration and submitted that the osteoblastic and induction theories are not mutually exclusive.

Platelet rich plasma (PRP) and other growth factors (fibrin glue) have been used to enhance the healing of cancellous cellular bone chips by several authors [36-40].

5. Free and pedicled compound grafts

Pedicled osteomyocutaneous flaps from the ribs, clavicle and scapular were previously popular[26, 40, 41]. However, the success rate was impaired by the limited arch of rotation, excess soft tissue, tenuous periosteal blood supply and inappropriate bone shape and volume[22, 26]. The development of microvascular reconstruction was therefore to minimize these limitations[27 - 29]. Furthermore, vascularized bone flaps are preferred by many surgeons over nonvascularised grafts and alloplasts because of the high rate of bone survival and low rate of infection [26]. However, other researchers[41 - 44]. have pointed out the rather high risk of complications associated with microvascular reconstruction. The major draw backs included:

a. Decrease in the number of available recipient vessels in patients who have had multiple neck operations.
b. The risk of complication is significant. Shaw[41] reported success rates of 94 to 95 percent and a re-exploration rate of 10 percent. However, Coleman and Wooden[42] reported complications in 85% of patients. Kroll et al[43] reported a complication rate of 50%. He submitted that the rate varies with the experience of the surgical team. Total failure in micro-vascular reconstruction is devastating as it will require another major surgery.
c. In patients who have had radiation treatment, the complication rates are increased three fold because both carotid and jugular vessels are included in the radiation field.
d. The aesthetic outcome is usually less than satisfactory[42- 44].

In view of this, the use of vascularized free flaps for all clinical situations has been likened to 'killing a fly with a sledge hammer'[45]. In resections of bone for benign lesions with preservation of periosteum, skin and mucosa, a nonvascularised graft should be the first option. Troulis et al[46] reported a high success rate and low morbidity using a staged protocol of resection, rigid fixation and delayed reconstruction.

6. Homograft – autograft combination

This entails the use of boiled, freeze dried or lyophilized / cryogenically treated cadaver mandible or rib as a crib to hold particles of autogenous cancellous bone removed from the iliac crest. The use of cryogenically treated cadaveric mandible has its greatest attraction in the reconstruction of the symphysis as it replicates its double parabolic arch[3, 46].

The future of mandibular reconstruction belongs to methods that minimizes or avoids the creation of secondary donor site defects and its associated morbidity. This will substantially reduce both the operating time and hospitalization cost. Two promising methods are distraction osteogenesis and tissue engineering.

7. Distraction Osteogenesis

Distraction osteogenesis (DO) involves creating an osteotomy (with preservation of the periosteum), followed by a latency period and the application of gradual incremental tension on the bony interface [47-54]. The gradual tension produces continuous bone formation (distraction osteogenesis). In addition, the adjacent soft tissues (mucosa, skin, nerves, blood vessels and cartilage) are concurrently distracted (distraction histiogenesis). There are six stages in distraction osteogenesis: [29, 55, 56]

I. Surgical / osteotomy phase.
ii. Latency period – 7 -10 days.
iii. Distraction phase – activation rate -0.4 - 0.5mm 2x daily.
iv. Consolidation phase – mineralization of the regenerate (3-4 weeks).
v. Appliance removal.
vi. Remodeling period – time from application of normal functional loads to complete maturation of the bone (10-12 months). For small defects of the mandible, the edges are simply placed together (compression) and distracted after a latent period (single phased DO). However, for large defects, a more technically sophisticated, multiple phased transport 'disc' distraction osteogenesis technique (TDDO) is applied[29, 53, 54]. This entails the application of a titanium reconstruction bar, single or multiple osteotomies of the native residual bone to create 'transport discs'. This transport disc is then gradually distracted along the inner aspect of the reconstruction bar by 1 or 2 distraction devices. Because of current limitations in equipment design, each phase of TDDO can generate up to 30-40mm of new bone. After consolidation, the transport disc can be further sectioned, the distraction device rotated 180 degrees, and further (phase 2) distraction applied to generate another 30mm. This technique permits the formation of an adequate volume and shape of the curved central part of the mandible. In addition, mucosa of adequate quantity and quality are formed concurrently[29, 55, 56]. This is important for eventual implant retained prosthetic rehabilitation.

Multivectoral distraction may allow accurate reproduction of the curvature and volume of the central part of the mandible which is the most difficult area to reconstruct. Exact reproduction of the shape and dimensions of the condyle may also be possible with tissue engineering and distraction osteogenesis. Schwatz and Relle[55] recently reported the use of transport distraction osteogenesis to reconstruct the ramus-condylar unit of the mandible. The limitations of this method of mandibular reconstruction include the multistage surgeries and the difficulty in controlling the vector of distraction in the mandibular arch region (symphysial and parasymphysial region)[57].

8. Bio-engineering (Tissue engineering)

This is the generation of living tissue to treat anatomical defects using laboratory molecular biology techniques and principles of material engineering. The chief advantage of tissue engineering is the avoidance of donor site defects and its associated morbidity[59-60]. Cells used in tissue engineering can be embryonic cells (pluripotent) and adult cells (pluripotent or committed). The sources of these cells can be autologous, allogeneic or xenogeneic. Allogeneic and xenogeneic grafts have the disadvantages of immunogenicity and rejection and possible disease transmission, however, the cells can be cultured and be constructed in advance. Autologous cells will require harvest, donation and in vitro culture. The strategy to create new bone involves the introduction of growth factors for osteoinduction, cells for osteogenesis and a scaffold for osteoconduction[58]. There are three main methods of tissue engineering[61-64].

a. Re - introduction into the body of cluster of stem cells to produce a specific function or tissue.
b. Implantation of an acellular biomaterial scaffold unto which native cells from adjacent uninjured tissue repopulate.
c. The implantation of preformed cellular- biomaterial constructs.
The biodegradable scaffold currently used in tissue engineering include collagen, demineralized bone matrix, hydroxyapatite, polylactic and polyglycolic acid copolymers and Pioloxamer 407[63, 64]. There are three main mechanisms of regeneration of osseous defects in tissue engineering[58, 64-67].
a. Osteogenesis (cells): formation of new bone by osteoprogenitor cells transferred to recipient (defect) site.
b. Osteoinduction (growth factors): formation of new bone by the activation of local mesenchymal cells to differentiate into bone forming cells.
c. Osteoconduction (scaffold): use of hydroxyapatite - collagen matrix and B-tricalcium phosphate. Essentially Wamke et al's[62] technique consisted of the application of computer assisted design to a 3-D CT scan of the defect. This was then transferred to a CAD operated 3 axis milling machine to produce teflon and titanium micromesh templates of the mandibular defect. Into this template were placed bone mineral blocks, 7mg of recombinant bone morphogenic protein 7 (BMP7), 1gm of bovine collagen type 1 and 20mls of patients bone marrow aspirate. This construct was then implanted in the lattisimus dorsi muscle for 7 weeks. This construct was harvested after 7 weeks as a free vascularised muscle bone flap to reconstruct a large mandibular defect. Scintigraphy and CT scan showed evidence of new bone formation in lattisimus dorsi and after transplantation to reconstruct the defect. However, a critical analysis of the three reports by Torroni[58] concluded that much work remains before these techniques can be used routinely in clinical practice. Moreover, the long term results of these three reports could not be ascertained as there were no long term survivors. He identified areas that require further research to include:

a. Identification of the ideal construct (scaffolds)
b. ideal types of biomaterial to be used as osteoconductor
c. selection of appropriate osteoinductor and its combination with the scaffold
d. the ideal prefabrication time
A promising animal study was reported by Abukawa et al[60]. they seeded mesenchymal cells unto a polylactate scaffold constructed in the shape of a mini-pig condyle. After 41 days of growth in tissue culture, the construct closely resembled the condyle in shape. Furthermore, the engineered tissue was hard and on histologic examination, bone tissue was evident. Kaban[56] has also reported complete regeneration of hemi-mandible in a child treated with interferon. Abukawa et al[63] recently reported the simultaneous autologous reconstruction of teeth and mandibular bone by autologous tissue engineering in a Yucatan minipig model.
Factors influencing success of autogenous or alloplastic reconstruction
The success or otherwise of mandibular reconstruction is influenced by several factors depending on the method employed to restore the defect.
Alloplastic reconstructions (titanium reconstruction plates)Shibahara et al[23] reported , three factors to adversely affect the long term success of reconstruction with titanium reconstruction plates;
1. Segmental defects that cross the midline.
2. Use of angular type plate to reconstruct the angle of the mandible.
3. Use of bone plates without bone grafting.
Kim and Donoff [24] also reported that anterior defects crossing the midline, use of plate only, previous irradiation and inadequate soft tissue covering necessitating use of flaps were associated with higher rates of wound dehiscence. Komisar[25], Lavertu et al[17] and Irish et al[27] reported that plate fractures occurred at the bent region in which stress was concentrated. However, Katakura et al[28] in a material analysis of fractured plates reported that the fractures occurred at the stress concentration region during mandibular movement-that is areas of repeated application of stress (fatique fracture). The authors also submitted that because plate fractures occurred within 11 months after reconstruction in cases in which the number of remaining teeth were large, secondary reconstruction with bone grafts should be performed as soon as possible in cases in which the occlusion is maintained.
Non-vascularized autogenous bone reconstruction For non-vascularized autogenous bone reconstruction, it is generally accepted that success is dependent on three main factors[3, 5, 12, 13, 29, 30]:
1. Adequate quantity and quality of the soft tissue bed. There must be sufficient soft tissue to cover the graft and it must be well vascularized because survival of the graft is dependent on re-vascularization from the soft tissue envelope. Implant rehabilitation also requires a thin layer of immobile mucosa fixed to the bone and covered by keratinized epithelium.
2. Stable (rigid) fixation. This will prevent movement between the graft and the host bone which may result in fibrous union in vascularised grafts and loss of graft in nonvascularised grafts.
3. Aseptic operating environment to prevent infection of the graft. Furthermore, the volume and contour of the grafted bone must mimic as close as possible the original resected bone. This is essential for restoration of the pre-morbid occlusion, aesthetics and eventual implant rehabilitation. Failure was associated with the presence of nonvital teeth/foreign bodies, haematoma formation, wound dehiscence and oral perforation[3, 5, 12, 13, 29, 30]. Lawson et al[30] identified oral perforation as being responsible for the difference in the success rate between immediate and delayed autogenous reconstructions. August et al[22] listed four clinical and radiographic criteria for bone graft success; a closed wound, freedom from infection, bony continuity and stability, long term maintenance of osseous bulk.
August et al[22] also reported greater blood loss during surgery, presence of post operative recipient site complications, diagnosis of malignant disease, and longer duration of suction drainage and use of sternocleidomastoid muscle flap for soft tissue augmentation as factors adversely influencing long term success of autogenous bone grafting. The authors also reported that failure (infection, nonunion and resorption) most often occur within the first year. Progrel [21] reported a high rate of failure when the defect is greater than 9cm. Free bone grafts are still highly recommended when the soft

tissues are healthy and the defect does not exceed 5cm[7, 64, 65]. Failure of mandibular reconstructions with autogenous bone grafts results in long-term functional as well as aesthetic impairments for the unfortunate patient **(Figure 4 a, b).**

Conclusion

It is the responsibility of surgeons to select appropriate methods of reconstruction for segmental defects of the mandible for different clinical situations. Knowledge of different methods with their advantages and limitations will allow him to optimize his choice.

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